International Workshop on η–Nucleus Physics

May 8–12, 2006, Jülich, Germany

Summary

and

Working Group Progress Report

Contents

[1]Work supported by DFG

[2]Supported by Forschungszentrum Juelich

1 Introduction

1.1 About the network

B. Höistad

Department of Radiation Sciences of Uppsala University, Uppsala, Sweden

This workshop is recognized as part of a European Community Integrated Infrastructure Initiative devoted to Hadron Physics (I3HP). This initiative contains several activities, one of them being the network EtaMesonNet which is created to exchange information on experimental and theoretical ongoing activities on η–physics at different European accelerator facilities and institutes, and is thereby promoting the infrastructure in Europe.

The present workshop is focused on specific aspects of η physics, namely the physics involved in the η–nucleon and the η–nucleus systems. It is very important to clarify, qualitatively as well as quantitatively, our present knowledge in this area, and try to formulate a strategy for how further knowledge should be gained from new advanced theoretical developments as well as from new experimental efforts. This workshop was mainly devoted to different theoretical issues, although a close connection with experimental data was always present. A substantial part of the workshop was given to discussions in connection with different selected talks. This form of the workshop turned out to be very fruitful and profitable.

The workshop was held in May 8-12, 2006, at the Forschungzentrum Jülich, enjoying kind hospitality and support from the IKP theory division. The financial support from the European Community-Research Infrastructure Activity under FP6 "Structuring the European Research Area" program (Hadron Physics, contract number RII3-CT-2004-506078), is gratefully acknowledged.

1.2 Scope of the workshop and results

C.Hanhart

Institut für Kernphysik (Theorie), Forschungszentrum Jülich

At the beginning of the Workshop a set of questions was posed to sharpen the focus of the meeting. These were:

1. What is the proper treatment of the η-N system within an η-nucleus calculation? In particular: can consistent equations be formulated that allow one to study a resonance propagator for this system?

2. What is the proper two body input to the few-body equations and what data can be used to constraint it? What do we know about the strength and energy dependence of the η-N interaction?

3. Inelastic channels: which ones are to be included and how? What is the origin of η-A imaginary part, how big is it and how can its size be determined unambiguously? This issue is closely connected to the previous one.

4. To what extent can an η-A study tell us something about the nature of the S11(1535)? Can we agree on some strategy to arrive possibly even at a model-independent answer to this question?

5. What needs to be done to get a consistent description of the η-d and η-^{3}He systems and how can one proceed to heavier systems such as η-α for which experimental information is available?

6. Are there other reactions that could shed light on the η-nucleus interaction?

Using this list as a basis, in this brief summary we try to present to what extent those questions were answered and where further research is necessary.

1: As long as the η-N scattering length is fixed and the effective range is large and negative, there seems to be very little sensitivity of the η-d scattering length to the details of the model used for η-N interaction. Nevertheless, the sensitivity to the value of the scattering length is large. The role of the effective range still needs to be explored systematically.

2,3: There was agreement that the large amount of high quality data now available for reactions with η-N final state should all be used to constrain the two-body dynamics. The role of the two-pion channels was identified to be sizable, but not essential for the two–body dynamics. The role of the 2-π channels as well as that of relativistic kinematics in the η–A reactions needs further systematic studies.

It became clear, that the influence of the $S_{11}(1650)$ on the η production reactions needs to be explored further and models should be faced with the NS_{11} transition form factors as measured at CLAS.

From the discussions it emerged that there is no conflict between a sizable imaginary part of the η-A scattering length induced by the pion channels, contrary to recent claims.

On the other hand is a small imaginary part a precondition for a (quasi)bound state. The issue on the size of the imaginary part can only be solved experimentally. Fortunately, this imaginary part can in principle be extracted model-independently from very near-threshold η-A production data. For the η–^3He system, the new ANKE and COSY-11 measurements might be of sufficient quality to settle this issue.

4: This remained unclear. If there is a dynamical singularity due to a bound state in the η-A system, this singularity will control the close-to-threshold dynamics and there is no clear cut connection to the properties of the S_{11}. However, there is still a chance that different models for the ηN dynamics will lead to different energy dependencies of the $\eta N \to \eta N$ transition — encoded especially in the effective range. Thus there might still be a chance to get more information on the S_{11} from η-A studies.

5: So far there exist microscopic calculations for η–d and η–^{3}He. Then there are effective models for the η-A interactions for nuclei heavier than Carbon. At present it is not clear how to connect these regimes.

6: It would be good to have data on the near-threshold η-A interaction for nuclei beyond ^{4}He. Although at present no systematic first principle calculations are possible for those systems it is important to investigate the trends of the low energy η-A interaction as a function of A. We know already that the energy dependence of η-d and η-^{3}He are quite similar, whereas that of η-^{4}He is significantly weaker. This might be interpreted as a more strongly bound system for η ^{4}He, since a more distant pole influences the near threshold regime less. To better understand the η-A system we would therefore need data on somewhat heavier nuclei than ^{4}He. Our current believe would be that the binding grows with growing A — this could be read off from the data directly.

The webpage of the workshop is http://www.fz-juelich.de/ikp/etanucleus/

2 Short summary of the talks

2.1 Photoproduction of η-mesons off nucleons and nuclei

B. Krusche[(a)],

[(a)] Department of Physics and Astronomy, University of Basel, Ch-4056 Basel, Switzerland

The talk has summarized experimental and partly also theory work on the photoproduction of η-mesons in view of the following topics:

1) Photoexcitation of the resonances on the free proton, in particular at low energies $S_{11}(1535)$ resonance, $D_{13}(1520)$ resonance.

2) Resonance contribution to η-photoproduction off the neutron, quasifree off neutrons bound in the deuteron, helium isotopes and coherent from deuteron

3) Threshold enhancements in η photoproduction off light nuclei and the search for η-mesic nuclei

4) Photoproduction of η-mesons off heavy nuclei in view of η-nucleus FSI (η - nucleon absortpion cross section) and the in-medium properties of the S_{11} resonance.

A summary on results published before 2003 concerning points 1), 2) is given in [1], a short summary on 3), 4) can be found in [2]. The following is a short summary of the discussed topics with the relevant references. There is certainly more relevant work, the reference list reflects only the work that has been adressed in some way in the talk.

- Photo-(Electro-)production of η off the free proton:
  - Measurements of the $p(\gamma, \eta)p$ differential and total cross sections:
    First isobar fit proposing S_{11} dominnance is given in [3], update with still mostly untagged pre-1990 data is given in [4]. Modern measurements with tagged photon beams: Tokyo (1988), 800 - 1000 MeV, angles of 45^o, 80^o, 100^o, 110^o [5]; Bonn (1995) AMADEUS (few data below 730 MeV) [6]; Mainz (1995) TAPS (energies up to 800 MeV, most precise threshold measurement) [7, 8, 9]; Grenoble (2002) GRAAL (energies up to 1.1 GeV) [10]; Jlab (2002) CLAS (energies up to 2 GeV) [11], Bonn (2005) Crystal Barrel (energies up to 3 GeV) [12].
  - Measurements of polarization observables:
    Photon beam asymmetry: Grenoble (1998) GRAAL [13]; Target asymmetry: Bonn (1998) PHOENICS [14]. Remark: Model analyses (isobar models [24], effective Lagrangian models [23]) find consistent solutions for angular distributions and beam asymmetry but then fail to reproduce the target asymmetry. It is shown in [24] that fits which enfore the target asymmetry result in an unexpectedly large and strongly energy dependent phase between S_{11} and D_{13} multipoles. This is an unsolved problem.

- Messurement of electroproduction cross sections: Bonn (1995) ELAN (only total cross section very close to photon point) [15]; Jlab (2001) CLAS $Q^2 \leq 1.3$ GeV^2 [16], Jlab (1999) HMS $Q^2 = 2.4$, 3.6 GeV^2 [17].
- Model analyses of data in particular in view of S_{11} resonances and $D_{13}(1520)$: Extraction of S_{11} parameters in particular electromagnetic helicity coupling $A^p_{1/2}$, see summary and discussion in [2], some of the above cited experimental papers quote numbers [5, 7, 10]. Further analysis e.g. in [18, 19, 20, 21, 22, 24, 25, 26]. Refs. [24, 26] analyse also the polarization data and extract branching ratio for $D_{13}(1520) \rightarrow N\eta$. Ref. [25] claims evidence for third S_{11} resonance from analysis of GRAAL data. Was not confirmed by later data and analyses (see e.g. [12]).
- Model predictions for the sensitivity of the $p(\gamma, \eta\gamma')p$ reaction to the magnetic moment of the $S_{11}(1535)$ resonance: [27, 28].
  Model predictions for the magnetic moment of the $S_{11}(1535)$: [27, 28, 29].
- Theory work concerned with the nature of the S_{11} resonance (apart from standard constituent quark models descriptions):
  Chiral constituent quark model with hyperfine interaction due to Goldstone boson exchange [30, 31]. Leads to quark-diquark clustering so that selection rules derived from quantum numbers of diqaurk favor η decay of $S_{11}(1535)$ and suppress η decay of $S_{11}(1650)$. $S_{11}(1535)$ is dynamiccaly generated ($K\Sigma$ molecular-like state) in chiral coupled channel calculations [32, 33].

• Photoproduction of η off light nuclei in view of neutron cross section and threshold enhancements:

- Measurements of quasi-free photoproduction off the neutron bound in the deuteron: Frascati 1969, untagged photon beam [34] found roughly $\sigma_n \approx \sigma_p$ in S_{11} region. All modern tagged photon experiments agree on $\sigma_n/\sigma_p \approx 2/3$ in $S_{11}(1535)$ range: Mainz (1995) TAPS [35]; Bonn (1997) Phoenics [36]; Mainz (2003) TAPS [37]. Threshold enhancements are discussed in [38]. First preliminary results indicate a strong rise of the neutron/proton ratio at higher incident photon energies: Grenoble (2004) GRAAL [39]; Bonn (2005) Crystal Barrel/TAPS [40]. Proton/neutron cross section ratio shows peak-like structure around invariant masses of 1.65 GeV. Probably due to resonance with strong photo-coupling to neutron, type of resonance not yet established.
- Measurement of coherent η photoproduction off the deuteron:
  Stanford 1969, untagged photon beam, only detection of recoil deuteron, found relatively large cross sections indicating a negligible iso-vector part [41]. Later tagged photon beam measurements with detection of recoil deuteron and η meson found much smaller cross sections indicating dominant iso-vector part. Mainz (1995) TAPS [35], only upper limits much below ref. [41]. Bonn (1997) PHOENICS [36] and Mainz (2001) TAPS [42] agree for most angles, beam energies, TAPS data lower than PHOENICS data for cm angles around 90^o.
- Measurement of quasi-free and coherent photoproduction of η off He nuclei:
  Quasifee of ^{4}He (Mainz/TAPS [43]) confirmed $\sigma_n/\sigma_p \approx 2/3$. No signal for coherent production seen in same experiment, only upper limits. Threshold behavior

discussed in [38]. Quasifree and coherent off ^{3}He (Mainz/TAPS 2004) [44, 45]: coherent contribution clearly identified, threshold enhancement of coherent part, indication of strong FSI, tentative indication for (quasi)bound state.

- Related results (threshold enhancements) for hadron induced reactions:
  in particular $pp \rightarrow pp\eta$ [46], $np \rightarrow d\eta$ [47, 48], $pd \rightarrow \eta^3$He [49, 52], $\vec{d}d \rightarrow \eta^4$He [50], and $pd \rightarrow pd\eta$ [51]. All reactions show more or less pronounced threshold enhancements. However, so far there is no conclusive evidence that the final state interaction is strong enough to form quasi-bound states.

- Experimental results for the explicit search of η-mesic nuclei:
  Pion induced reactions on oxygen nuclei, search for kinematical peak from two-body final states in $\pi^+ +^{16} O \rightarrow p +^{15}_{\eta} O$ [53] and in $\pi^+ +^{18} O \rightarrow \pi^- +^{18}_{\eta} Ne$ [54]. No evidence reported.
  Claim of positive result from the photon induced reaction chain $\gamma +^{12} C \rightarrow N +_{\eta} (A-1) \rightarrow N + \pi^+ + n + (A-2)$ for A=11 nuclei (carbon,beryllium) [55, 56], not yet supported by other experiments.
  Result from photoproduction on ^{3}He [44, 45], must be confirmed with better statistics.

- Model calculations of η photoproduction off deuteron and He nuclei:
  Quasifree and coherent photoproduction off the deuteron and deuteron threshold effects e.g.: [58, 59, 60, 61, 62, 63, 64, 65, 66]. Photoproduction off the three-nucleon system e.g.: [67, 68, 69, 70].

- Predictions for existence of η-mesic nuclei, analysis of ηN scattering length:
  Early results for scattering length (a=0.27+i0.22) and possible existence of η-mesic nuclei with $A > 10$: [71, 72]. Many new results of scattering length due to availability of more precise data (majority finds larger values of real part but span the entire range from 0.2 - 1.0, most cluster between 0.5 - 0.8), resulting in much discussion about existence of light η-mesic nuclei (in particular ^{2}H, ^{3}H, ^{3}He, ^{4}He): [73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85] and probably more.

- Photoproduction off heavy nuclei, η-nucleus FSI and S_{11} in-medium properties:

  - Measurements of η-photoproduction off heavy nuclei:
    Early untagged data from Frascati [86]. First precise measurement from threshold to $\approx$800 MeV Mainz (1996) TAPS [87]. Established $A^{2/3}$ scaling of cross section, i.e. strong FSI, found ηN absorption cross section of $\approx$30 mb, mean-free path $\lambda \approx 2$ fm. No significant S_{11}(1535) modification. Extension to energies up to $\approx$ 1 GeV from KEK [88, 89] report at most small in-medium effects. Most recent data from LNS Tohoku University up to 1.1 GeV [90] and from Bonn (Crystal Barrel/TAPS) up to 2 GeV, covering entire S_{11} range [91]. Some additional results and discussion of mass dependence etc. in comparison to other meson production channels in [92, 93]. Seem to indicate that re-scattered contributions from nuclear volume show stronger suppession of second resonance bump than quasi-free surface contributions.

– Model calculations for η-photoproduction off heavy nuclei:
Comparison of results from cascade Monte Carlo calculations [94] or BUU calculations [95, 96, 97, 98] to data show no need for significant in-medium modification of S_{11}. Predictions for in-medium spectral function of S_{11} from self-consistent calculations show only small in-medium effects [99].

References

[1] B. Krusche and S. Schadmand, Prog. Part. Nucl. Phys. **51** (2003) 399

[2] B. Krusche, Prog. Part. Nucl. Phys., *Prog. Part. Nucl. Phys.* 55 (2005) 46

[3] H.R. Hicks, S.R. Deans, D.T. Jocabs, P.W. Lyons, D.L. Montgomery, *Phys. Rev.* D 7 (1973) 2614

[4] F. Tabakin, S.A. Dytman, A.S. Rosenthal, *Proceedings of the Excited Baryons Conf., Troy, New York, USA 4-6 August 1988, Edts. G. Adams, N.C. Mukhopadhyay, P. Stoler, World Scientific* (1989) 168

[5] S. Homma et al., *J. Phys. Soc. Japan* 57 (1988) 828

[6] J.W. Price et al., *Phys. Rev.* C 51 (1995) R2283

[7] B. Krusche et al., *Phys. Rev. Lett.* 74 (1995) 3736

[8] B. Krusche et al., *Phys. Rev. Lett.* 75 (1995) 3023

[9] B. Krusche et al., *Z. Phys.* A 351 (1995) 237

[10] F. Renard et al., *Phys. Lett.* B 528 (2002) 215

[11] M. Dugger et al., *Phys. Rev. Lett.* 89 (2002) 222002

[12] V. Credé et al.,*Phys. Rev. Lett.* 94 (2005) 012004

[13] J. Ajaka et al., *Phys. Rev. Lett.* 81 (1998) 1797

[14] A. Bock et al., *Phys. Rev. Lett.* 81 (1998) 534

[15] B. Schoch, *Prog. Part. Nucl. Phys.* 34 (1995) 43

[16] R. Thompson et al., *Phys. Rev. Lett.* 86 (2001) 1702

[17] C.S. Armstrong et al., *Phys. Rev.* D 60 (1999) 052004

[18] G. Knöchlein, D. Drechsel, L. Tiator, *Z. Phys.* A 352 (1995) 327

[19] C. Sauermann, B.L. Friman, W. Nörenberg, *Phys. Lett.* B 341 (1995) 261

[20] Zhenping Li, *Phys. Rev.* D 52 (1995) 4961

[21] M. Benmerrouche, N.C. Mukhopadhyay, J.F. Zhang, *Phys. Rev. Lett.* 77 (1996) 4716

[22] B. Krusche, N.C. Mukhopadhyay, J.F. Zhang, M. Benmerrouche, *Phys. Lett.* B 397 (1997) 171

[23] N.C. Mukhopadhyay and N. Mathur, *Phys. Lett.* B 444 (1998) 7

[24] L. Tiator, D. Drechsel, G. Knöchlein, C. Bennhold, *Phys. Rev.* C 60 (1999) 035210

[25] B. Saghai and Z. Li, *Eur. Phys. J.* A 11 (2001) 217

[26] W.-T. Chiang, S.N. Yang, L. Tiator, D. Drechsel, *Nucl. Phys.* A 700 (2002) 429

[27] W.-T. Chiang, S.N. Yang, M. Vanderhaeghen, D. Drechsel, *Nucl. Phys.* A 723 (2003) 205

[28] T. Hyodo, S.I. Nam, D. Jido, A. Hosaka, nucl-th *0305023/* (2003)

[29] J. Liu, J. He, and Y.B. Dong, *Phys. Rev.* D 71 (2005) 094004

[30] L.Ya. Glozman and D.O. Riska, *Phys. Rep.* 268 (1996) 263

[31] L.Ya. Glozman and D.O. Riska, *Phys. Lett.* B 366 (1996) 305

[32] N. Kaiser, P.B. Siegel, W. Weise, *Phys. Lett.* B 362 (1995) 23

[33] N. Kaiser, T. Waas, W. Weise, *Nucl. Phys.* A 612 (1997) 297

[34] C. Bacci et al., *Phys. Lett.* B 28 (1969) 687

[35] B. Krusche et al., *Phys. Lett.* B 358 (1995) 40

[36] P. Hoffmann-Rothe et al., *Phys. Rev. Lett.* 78 (1997) 4697

[37] J. Weiss et al., *Eur. Phys. J.* A 16 (2003) 275

[38] V. Hejny et al., *Eur. Phys. J.* A 13 (2002) 493

[39] V. Kouznetsov et al., Proceedings of NSTAR 2004, Grenoble, France 2004 (2004) 197

[40] I. Jaegle et al., Proceedings of NSTAR 2005, Tallahasse, USA (2005) ,in press

[41] R.L. Anderson, R. Prepost *Phys. Rev. Lett.* 23 (1969) 46

[42] J. Weiss et al., *Eur. Phys. J.* A 11 (2001) 371

[43] V. Hejny et al., *Eur. Phys. J.* A 6 (1999) 83

[44] M. Pfeiffer et al., *Phys. Rev. Lett.* 92 (2004) 252001

[45] M. Pfeiffer et al., *Phys. Rev. Lett.* 94 (2005) 049102

[46] H. Calén et al., *Phys. Lett.* B 366 (1996) 39

[47] F. Plouin et al., *Phys. Rev. Lett.* 65 (1990) 690

[48] H. Calén et al., *Phys. Rev. Lett.* 80 (1998) 2069

[49] B. Mayer et al., *Phys. Rev.* C 53 (1996) 2068

[50] N. Willis et al., *Phys. Lett.* B 406 (1997) 14

[51] F. Hibou et al., *Eur. Phys. J.* A 7 (2000) 537 ;

[52] R. Bilger et al., *Phys. Rev.* C 65 (2002) 044608

[53] R.E. Chrien et al., *Phys. Lett.* B 60 (1988) 2595

[54] J. D. Johnson et al.,*Phys. Rev.* C 47 (1993) 2571

[55] G.A. Sokol et al., *nucl-ex/* 0011005 (2000)

[56] G.A. Sokol et al., *nucl-ex/* 0106005 (2001)

[57] N.C. Mukhopadhyay, J.F. Zhang, M. Benmerrouche, *Phys. Lett.* B 364 (1995) 1

[58] A. Fix, H. Arenhövel, *Z. Phys.* A 359 (1997) 427

[59] F. Ritz, H. Arenhövel, *Phys. Lett.* B 447 (1999) 15

[60] A. Fix, H. Arenhövel, *Phys. Lett.* B 492 (2000) 32

[61] A. Fix, H. Arenhövel, *Eur. Phys. J.* A 9 (2000) 119

[62] F. Ritz, H. Arenhövel, *Phys. Rev.* C 64 (2001) 034005

[63] A. Sibirtsev et al., *Phys. Rev.* C 64 (2001) 024006

[64] A. Fix, H. Arenhövel, *Nucl. Phys.* A 697 (2002) 277

[65] A. Sibirtsev et al., *Phys. Rev.* C 65 (2002) 067002

[66] A. Fix, H. Arenhövel, *Eur. Phys. J.* A 19 (2004) 275

[67] A. Fix, H. Arenhövel, *Phys. Rev.* C 66 (2002) 024002

[68] A. Fix, H. Arenhövel, *Phys. Rev.* C 68 (2003) 190

[69] A. Sibirtsev et al., *Phys. Rev.* C 70 (2004) 047001

[70] C. Hanhart, *Phys. Rev. Lett.* 2005 (049101) 94 2005

[71] R.S.Bhalerao and L.C.Liu, *Phys. Rev. Lett.* 54 (1985) 865

[72] L.C.Liu and Q.Haider, *Phys. Rev.* C 34 (1986) 1845

[73] T.Ueda, *Phys. Rev. Lett.* 66 (1991) 297

[74] T.Ueda, *Phys. Lett.* B 291 (1992) 228

[75] C.Wilkin, *Phys. Rev.* C 47 (1993) R938

[76] S.A.Rakityanski et al., *Phys. Lett.* B 359 (1995) 33

[77] S.A. Rakityanski et al., *Phys. Rev.* C 53 (1996) R2043

[78] A.M. Green and S. Wycech, *Phys. Rev.* C 54 (1996) 1970

[79] A.M. Green and S. Wycech, *Phys. Rev.* C 55 (1997) R2167

[80] N.N. Scoccola, D.O. Riska, *Phys. Lett.* B 444 (1998) 21

[81] A.M. Green and S. Wycech, *Phys. Rev.* C 60 (1999) 35208

[82] N.V. Shevchenko et al., *Eur. Phys. J.* A 9 (2000) 143

[83] V. Yu. Grishina et al., *Phys. Lett.* B 475 (2000) 9

[84] H. Garcilazo and M.T. Pena, *Phys. Rev.* C 63 (2001) R21001

[85] A. Sibirtsev et al., *Phys. Rev.* C 65 (2002) 044007

[86] C. Bacci et al., *Lett. Nuovo Cimento* 8 (1969) 391

[87] M. Röbig-Landau et al., *Phys. Lett.* B 373 (1996) 45

[88] T. Yorita et al. *Phys. Lett.* B 476 (200) 226

[89] H. Yamazaki et al., *Nucl. Phys.* A 670 (2000) 202c

[90] T. Kinoshita et al., nucl-ex/ 0509022 (2005)

[91] T. Mertens et al., priv. com. (2006)

[92] B. Krusche et al., *Eur. Phys. J.* A 22 (2004) 277

[93] B. Krusche et al., *Eur. Phys. J.* A 22 (2004) 347

[94] R.C. Carrasco, *Phys. Rev.* C 48 (1993) 2333

[95] A. Hombach et al., ZPA 352 (1995) 223

[96] J. Lehr, M. Effenberger, U. Mosel, *Nucl. Phys.* A 671 (2000) 503

[97] J. Lehr and U. Mosel, *Phys. Rev.* C 64 (2001) 042202

[98] J. Lehr, M. Post and U. Mosel, *Phys. Rev.* C 68 (2003) 044601

[99] M. Post, J. Lehr, U. Mosel, *Nucl. Phys.* A 741 (2004) 81

2.2 The Crystal Ball data on π^0, $2\pi^0$, and η pion– and photoproduction on complex targets

A. Starostin

University of California, Los Angeles, CA 90095-1547, USA

A unique set of data on light, neutral, meson production by π^- on complex targets has been obtained by the Crystal Ball collaboration at Brookhaven National Laboratory. The data include angular distributions, distributions of kinetic energy and missing mass for $\pi^- A \to \pi^0 X$ and $\pi^- A \to \eta X$, as well as the invariant mass distributions and the Dalitz plots for $\pi^- A \to 2\pi^0 X$. The data were obtained for two incident π^- beam momenta (408 MeV/c, and 750 MeV/c) on four different targets: H_2, C, Al, and Cu. The analysis of the single and double pion production reveals significant pion rescattering and absorption in complex nuclei. We concluded that the rescattering and absorption are mainly responsible for the observed changes in the shape of the $2\pi^0$ invariant mass for the complex targets. Our hydrogen data indicate that the dominant mechanism of $2\pi^0$ production on a proton is via the intermediate $\Delta(1232)$ state. The contribution of the alternative mechanism via the intermediate $f_0(600)$ meson is not significant. The results obtained on complex targets show a strong nuclear absorption of the $\Delta(1232)$. This may enhance the fraction of the $2\pi^0$ events produced via the $f_0(600)$. See Refs [1,2,3] for details.

New Crystal Ball/TAPS data has been obtained in 2005 at the Mainz Microtron Facility. The experiment uses the MAMI real photon beam with the continuous energy spectrum from 100 MeV to the maximum energy of 819 MeV. The list of the targets include H_2, D_2, Li, C, HO_2, Ca, and Pb. The data were obtained for the following reactions: $\gamma A \to \pi^0 X$, $\gamma A \to \eta X$, and $\gamma A \to 2\pi^0 X$. Analysis of the experimental data is in progress.

References

[1] A. Starostin *et al.*, Phys. Rev. Lett. **85**, 5539 (2000).

[2] A. Starostin *et al.*, Phys. Rev. C **66**, 055205 (2002).

[3] S. Prakhov *et al.*, Phys. Rev. C **72**, 015203 (2005).

2.3 Investigation of the ^{3}He-η Final State in dp-Reactions at ANKE

T. Mersmann

Institut für Kernphysik, Universität Münster, Münster, Germany

The existence of η-mesic ^{3}He-nuclei is still an open issue of research [1,2,3]. To investigate the possibility of the formation of such a bound system, production measurements with one η meson and the ^{3}He-nucleus in the final state are of great interest. By studying this system at low excess energies, information about the final state interaction and therefore about the scattering length of the η-nucleus system can be gained. The latter one is closely related to the properties of such a possible bound state and has to be determined with high precision.

The available data sets for p+d$\rightarrow$^{3}He+η production experiments in the close vicinity of the threshold [4,5] expose discrepancies, which currently forbid the extraction of scattering length information with sufficient precision. Therefore, the reaction d+p$\rightarrow$^{3}He+η has been investigated at the ANKE spectrometer [6] using a continuously ramped accelerator beam at excess energies ranging from below threshold up to Q=+12 MeV. Due to the full geometrical acceptance of the ANKE spectrometer high statistic data on this reaction have been obtained. Additionally, data at excess energies of Q = 20, 40 and 60 MeV have been recorded in order to determine total cross sections and to investigate contributions from higher partial waves.

The identification of ^{3}He-nuclei is done using scintillation wall information for an energy-loss-vs.-momentum method. The momenta can be extracted at the magnetic spectrometer ANKE with high accuracy, which allows a determination of the excess energy with high precision. The identification of the η-meson production itself is done using the missing mass technique. Here the background subtraction can be performed using the data obtained at sub-threshold energies. To extract total and differential cross sections the luminosity is determined using the simultaneously measured *dp*-elastic scattering. First data on the excitation function from threshold up to an excess energy of Q$\sim$10 MeV are shown with an energy resolution of ΔQ$\sim$0.25 MeV.

References

[1] A. Sibirtsev *et al.*, Phys. Rev. C 70, 047001 (2004).

[2] A. Sibirtsev *et al.*, Eur. Phys. J. A 22 495 (2004).

[3] M. Pfeiffer *et al.*, Phys. Rev. Lett. 92, 252001 (2004).

[4] J. Berger *et al.*, Phys. Rev. Lett. 61, 919 (1988).

[5] B. Mayer *et al.*, Phys. Rev. C 53, 2068 (1996).

[6] A. Khoukaz, T. Mersmann, COSY Proposal 137 (2004).

2.4 η-nucleus bound state search at COSY

D. Kirillov

Institut für Kernphysik, FZ Jülich, Germany

A large acceptance plastic scintillator detector 'ENSTAR' [1,2] has been designed and built for studies of a new form of nuclear matter - 'η-mesic' nuclei (ηA). These are bound systems, consisting of an η-meson and a nucleus. The η-mesic nuclei, which are solely the result of strong interactions unlike the pionic atoms, are a new kind of atomic nuclei and their research has fundamental significance in studying in-medium properties of hadrons, in particular, medium modification of meson masses. The experimental confirmation of the existence of such η-bound system will lead to new possibilities of studying the interaction between a nucleus and the short lived (10-18 s) η meson.

The predicted cross section for such reactions is extremely low (few nbarn) [3,4,5]. In order to clearly identify such low cross section events in the presence of a large background from other competitive processes, it is necessary to make coincidence measurements of the ejectile nucleus with the decay products of the η-mesic nucleus.

The in-beam testing of the detector in full assembled condition was done at COSY, Juelich in March 2004 [6]. Different nuclear reactions (pp elastic scattering, $p+p \to d+\pi^+$, p + 'heavy target') were used, in addition cosmic ray data were collected. Coincidence data (coincidence between ENSTAR and Big Karl spectrometer, a 2-fold coincidence between different elements in ENSTAR) were also collected.

During the beamtime in May 2005 data on $p+^{27}Al \to ^3He+^{25}Mg_\eta$ where obtained. Big Karl was used to spectroscopy and get η-nucleus missing mass spectra. 'ENSTAR' was used to reduce the background, making triple coincidences with η-mesic nucleus decay products through the chain $\eta + N \to N^* \to p + \pi^-$. After the data analysis it was considered, that low statistics does not allow to see the η-bound nucleus signature. Upper limit for the cross section was preliminary detemined to be 0.7 nbarn.

References

[1] B.J. Roy et al; Phys. Lett. B 550(2002) 47

[2] B.J. Roy et al; BARC external report no. BARC/2000/E/004, Bhabha Atomic Research Centre, Mumbai-400085, India

[3] L.C. Liu; private communication

[4] R.S. Bhalerao et al; Phys. Rev. Lett. 54 (1985) 865

[5] C. Wilkin, Phys. Rev. C 47 (1993) R398

[6] B.J. Roy et al; Cosy proposal No.50.3, COSY, Jülich

2.5 Search for the $\eta - {}^3$He and $\eta - {}^4$He bound states at COSY-11

Pawel Moskal

Institute of Physics, Jagellonian University
IKP, Forschungszentrum Jülich

Presented talk comprises ideas of the search for the $\eta - {}^3$He and $\eta - {}^4$He bound states by means of the COSY-11 facility at the cooler synchrotron COSY. Detailes concerning a proposed method of measurement and the preliminary results have been reported at the COSY Advisory Committee Meeting [1] and at the ETA05 Workshop [2], and the interested reader is referred to these reports. Here instead due to the space limitation only abstracts and references are given.

We propose to search for the $\eta - {}^4$He bound state via a measurement of the excitation functions for the $dd \rightarrow {}^3\mathrm{He}p\pi^-$ and $dd \rightarrow {}^3\mathrm{He}n\pi^0$ reactions where the outgoing $p - \pi^-$ or $n - \pi^0$ pair originates from the conversion of the η meson on a neutron inside the ^{4}He nucleus and the ^{3}He ejectile is an "observer". Precise determination of the profile of the expected Breit-Wigner distribution in the excitation curve will allow to determine the binding energy and the width of the $\eta - {}^4$He state. A simultaneous detection of all ejectiles is not feasible in practice neither at the COSY-11 nor at the WASA setup. However, a kinematically complete measurement can be very well performed by the detection of the ^{3}He nucleus and one of the other outgoing particle and by using a well settled missing mass technique. For this aim we intend to study the $dd \rightarrow {}^3\mathrm{He}p\pi^-$ reaction at the COSY-11 facility where the outgoing ^{3}He and protons can be measured with a better accuracy and larger angular range in comparison to the WASA detector. Besides, under assumption that in the $d - d$ center of mass system the ^{3}He ejectiles are emitted with the Fermi momenta, the COSY-11 acceptance for detecting ^{3}He is essentially larger than the one of WASA. On the other hand, contrary to the COSY-11, the WASA detector allows to measure the ${}^3\mathrm{He}n\pi^0$ decay channel. Therefore, in the next step in the near future we propose to conduct the measurement of the excitation function of the $dd \rightarrow {}^3\mathrm{He}n\pi^0$ reaction at the WASA-at-COSY facility. Both experiments will be performed taking advantage of the possibility of slow ramping of the COSY deuteron beam.

Preliminary results from $dp \rightarrow {}^3\mathrm{He}\,X$, $(X = \pi^0, \eta)$ measurements near the η production threshold have been presented. The data were taken during a slow ramping of the COSY internal deuteron beam scattered on a proton target. The ^{3}He ejectiles were registered with the COSY-11 detection setup. The ongoing data analysis should deliver high precision data for the $dp \rightarrow {}^3\mathrm{He}\,\eta$ total and differential cross sections for the excess energies in the range from threshold up to 9 MeV. The preliminary excitation function for the reaction $dp \rightarrow {}^3\mathrm{He}\,\pi^0$ does not show any structure which could originate from the decay of ${}^3\mathrm{He} - \eta$ bound state. We present also a threshold excitation curve for the $dp \rightarrow {}^3\mathrm{He}\,X$ channel. Contrary to corresponding results from SATURNE we see no cusp in the vicinity of the η threshold [2].

References

[1] J. Smyrski, P. Klaja, P. Moskal, COSY Proposal **No. 160**
available at: http://www.fz-juelich.de/ikp/publications/List_of_all_COSY-Proposals.shtml

[2] J. Smyrski et al., Acta Phys. Slovaca **56** (2006) 213 [nucl-ex/0603023]

[3] Q. Haider and L. C. liu, Phys. Lett. **B172** (1986) 257

[4] S. D. Bass and A. W. Thomas, Phys. Lett. **B634** (2006) 368

[5] H. Calén et al., **80** (1998) 2069

[6] C. Wilkin, Phys. Rev. **C47** (1993) R938

[7] N. Willis et al., Phys. Lett. **B406** (1997) 14

[8] S. Wycech, A. M. Green and J. A. Niskanen, Phys. Rev. **C52** (1995) 544

[9] N. N. Scoccola and D. O. Riska, Phys. Lett. **B444** (1998) 21

[10] M. Pfeiffer et al., Phys. Rev. Lett. **92** (2004) 252001

[11] C. Hanhart, e-Print Archive: hep-ph/0408204

[12] J. G. Fetkovich et al., Phys. Rev. **D6** (1972) 3069

2.6 On the possibility of measuring the He-η bound state with WASA at COSY

Jozef Zlomanczuk

Department of Radiation Sciences of Uppsala University, Uppsala 27-03-2006

Threshold enhancements in reactions leading to the d-η [1,2,3,4], ^{3}He-η [5,6] and ^{4}He-η [7,8] final states clearly show the low energy η-nucleus interaction to be strong and attractive. These enhancements might turn out to be signals for η-nucleus quasi-bound or bound states that were predicted for nuclei as light as ^{2}H [9] and ^{3}He [10,11,12,13,14,15]. The effect is expected to be stronger for larger number of nucleons and some authors expect the η-nucleus bound states to exist only for heavier nuclei [16,17,18,19]. Recently, a first experimental observation of the ^{3}He-η bound state was reported in the η photoproduction reaction on ^{3}He [20]. Difference between excitation functions of the $\gamma^3\mathrm{He} \to \pi^0$p+X reaction measured for two ranges of the π^0-p relative angle in the γ-^{3}He center of momentum system, 170^0-180^0 and 150^0-170^0, revealed a structure, which was interpreted as a signature of a ^{3}He-η bound state with binding energy of a few MeV and width close to 26 MeV. However, it has been argued that due to limited statistics the result may be equally well interpreted as a virtual state or merely a cusp effect [21]. To resolve this ambiguity more accurate measurements are needed. In order to shed more light on the possibility of existence of η-nucleus bound systems for light nuclei, one could study η-^{4}He system in the reactions:

dd $\to$ ^{3}He$n\pi^0$, dd$\to$ ^{3}He$p\pi^-$,

in the energy range from some 60 MeV below dd $\to$ ^{4}He-η threshold to some 40 MeV above threshold. In order to provide small binning in the total energy, the measurements could be carried out with the WASA detector on slow ramp of magnetic field of the COSY, resulting in the beam momentum uniformly distributed over the desired range.

The Monte Carlo simulation of the experiment presented in this contribution shows that the expected resolution of the WASA detector is sufficient to unambigously identify the possible η-^{4}He bound state. Also some estimation of the effect to background ratio is given.

References

[1] F. Plouin et al., *Nucl. Phys.* A 302, 413 (1978).

[2] F. Plouin, P. Fleury, and C. Wilkin, *Phys. Rev. Lett.* 65, 690 (1990).

[3] H. Calén et al., *Phys. Rev. Lett.* 79, 2642 (1997).

[4] H. Calén et al., *Phys. Rev. Lett.* 80, 2069 (1998).

[5] J. Berger et al., *Phys. Rev. Lett.* 61, 919 (1988).

[6] B. Mayer et al, *Phys. Rev.* C 53, 2068 (1996).

[7] R. Frascaria et al., *Phys. Rev.* C 50, R537 (1994).

[8] N. Willis et al., *Phys. Lett.* B 406, 143 (1997).

[9] T. Ueda, Phys. *Rev. Lett.* 66, 297 (1991); Physica Scripta 48, 68 (1993).

[10] S. Wycech, A.M. Green, and J.A. Niskanen, *Phys. Rev.* C 52, 544 (1995).

[11] S.A. Rakityansky, S.A. Sofianos, W. Sandhas, and V.B. Belyaev, *Phys. Lettd* B 359, 33 (1995).

[12] V.B. Belyaev, S.A. Rakityansky, S.A. Sofianos, M. Braun, and W. Sandhas, *Few. Body. Syst. Suppl.* 8, 309 (1995).

[13] S.A. Rakityansky, S.A. Sofianos, M. Braun, V.B. Belyaev and W. Sandhas, *Phys. Rev.* C 53, R2043 (1996).

[14] A. Fix and H. Arenhvel, *Phys. Rev.* C 66, 024002 (2002).

[15] C. Wilkin, Phys. *Rev. C.* 47, R938 (1993).

[16] Q. Haider and L.C. Liu, *Phys. Lett.* B 172, 257 (1986).

[17] L.C. Liu and Q. Haider, *Phys. Rev.* C 34, 1845 (1986).

[18] H.C. Chiang, E. Oset, and L.C. Liu, *Phys. Rev.* C 44, 738 (1991).

[19] Q. Haider and L.C. Liu, *Phys. Rev.* C 66, 045208 (2002).

[20] M. Pfeiffer et al., *Phys. Rev. Lett.* 92 (2004) 252001.

[21] C. Hanhart, *arXiv:hep-ph/0408204 v1* 18 Aug 2004. 22.

2.7 Practical unitary πNN theory with full dressing

A. N. Kvinikhidze and B. Blankleider.

Mathematical Institute of Georgian Academy of Sciences, Tbilisi, Georgia,
Flinders University of South Australia, Adelaide, Australia.

The complete theoretical solution of the πNN-like three-body problem is a very important theoretical development which, unfortunately, has so far not been utilized in calculations. The πNN-like three-body problem is beyond quantum mechanical considerations as it involves the pure QFT phenomenon of particle poduction and absorbtion. Mathematicaly this is reflected in the presence of extra disconnected kernels in the πNN equations which just correspond to pion production on one nucleon and absorption on the other, in addition to the purely quanum-mechanical disconected pair-wise (elastic) interactions. These extra kernels change drastically the dynamics of the three-body system, and in addition, generate dressings of the nucleons. Appart from the difficulty of treating these new kernels to rearrange the equations analogously to the Faddeev rearrangement, there appears a problem of proper renormalization caused by dressing of the nucleons. The latter cannot be solved using traditional trunction of the Hilbert space to some maximum number of pions.

All these problems are solved, and a formulation of the πNN problem is presented in [1] where unitary equations are obtained without having to truncate the Hilbert space to some maximum number of pions. Consequently, all possible dressings of one-particle propagators and vertices are retained in our model. In this way we overcome the renormalization problems inherent in essentially all previous NN theories. The final form of the derived equations is very convenient for numerical solution as basically the same methods as applied to the Faddeeev equations are needed.

References

[1] A.N. Kvinikhidze, B. Blankleider. Phys.Lett.B307:7-12 (1993)

[2] A.T. Stelbovics, M. Stingl, Nucl.Phys. A294, 391 (1978)

2.8 Full two body amplitudes as input for the η meson production in nucleon-nucleon scattering

A. Švarc, S. Ceci and B. Zauner

Ruđer Bošković Institute, Bijenička cesta 54, 10000 Zagreb, Croatia.

Theoretical models for calculating meson production processes in nucleon-nucleon scattering require two-body meson-nucleon amplitudes with at least one particle off-mass-shell as input. As experiments enable us only to obtain the amplitudes with all four particles on-mass shell, we need the model for the off-mass-shell extrapolation. In principle, one should discuss the full invariant amplitude, in practice it is done on the level of partial waves only. Early attempts have been done in $pp \to \pi d$ process [1, 2] where the on-shell amplitudes with the πN cm energy calculated with the full off-mass-shell kinematics were used as the off-mass-shell values. These attempts have been followed by representing the S_{11} partial wave within the framework of separable potential model. In this approach the free model-parameters are obtained by fitting PWA results, and are used to calculate the input meson-nucleon form factors using the full off-mass-shell kinematics [3, 4].

We offer the explicit analytic form of the partial-wave T-matrix emerging from the two-body coupled-channel formalism [5, 6], which describes all available experimental data in πN elastic and $\pi N \to \eta N$ channels, and may therefore serve as a basic expression which determines the behavior of partial wave amplitudes when one or two particles are going off-mass-shell:

$$\hat{T}(s, q_i, q_f) = \sqrt{Im\hat{\Phi}(q_i)} \cdot \hat{\gamma}^{\mathrm{T}} \cdot \frac{\hat{G}_0(s)}{I - \left[\hat{\gamma} \cdot \hat{\Phi}(q_i, q_f) \cdot \hat{\gamma}^{\mathrm{T}}\right] \cdot \hat{G}_0(s)} \cdot \hat{\gamma} \cdot \sqrt{Im\hat{\Phi}(q_f)}. \qquad (1)$$

q_i and q_f are the incoming and outgoing meson-nucleon cm momenta and s is the meson-nucleon cm energy. This is a symbolic matrix equation with free parameters contained in the channel-resonance coupling matrix $\hat{\gamma}$ and in the values of the free Green function propagator poles. The recommended representation of the on-shell experimental data in principle fully defines the recipe how to go off-mass-shell with either particle.

This recipe, however, requires to be tested; so we encourage all physicists involved in any theoretical considerations involving η-meson production to use as input to their calculation. In order to simplify your efforts, Mathematica 5.2 codes for obtaining the analytic form of partial wave T-matrices, together with the required input parameter file, or the Mathematica 5.2 table $T_{ab}(i, j, k)$ for the $\hat{T}(s, q_i, q_f)$ matrix with required density are available upon request for all partial waves [7], and will be send to the interested person immediately.

References

[1] W. Grein, A. König, P. Kroll, M.P. Locher and A. Švarc, Annals of Physics **153** (1984) 301.

[2] M. Batinić, T.-S.H. Lee, M.P. Locher, Yang Lu and A. Švarc, Phys. Rev. C **50** (1994) 1300.

[3] H. Garcilazo and M.T. Peña, Phys. Rev. C **66** (2002) 034606.

[4] H. Garcilazo and M.T. Peña, Phys. Rev. C **72** (2005) 014003.

[5] M. Batinić, I. Šlaus, A. Švarc and B.M.K. Nefkens, Phys. Rev. **C51**, 2310 (1995); M. Batinić, I. Dadić, I. Šlaus, A. Švarc, B.M.K. Nefkens and T.S.-H. Lee, Physica Scripta **58**, 15 (1998).

[6] http://www.fz-juelich.de/ikp/etanucleus/

[7] e-mail:alfred.svarc@irb.hr

2.9 Why the η-nucleus scattering length can be small?

J. A. Niskanen

Department of Physical Sciences, PO Box 64, FIN-00014 University of Helsinki, Finland

Most calculations of η^3He scattering yield rather large imaginary parts of the scattering length, mostly $\Im a \geq 2$ fm and $\Im a \geq |\Re a|$ [1–4]. Even if $\Re a$ were negative, considered often as a sign of possible binding, this is bad news for finding bound states. Firstly, the bound state could be too broad to observe and secondly even the actual necessary conditions for the existence of a bound state $|\Re a| > \Im a$ [5] (expanded further to $\Re[a^3(a^* - r_0^*)] > 0$ in Ref. [6]) are not satisfied.

However, two recent global analyses of $pd \to \eta^3$He data give mutually consistent results $a = \pm 4.3 \pm 0.3 + i\,(0.5 \pm 0.5)$ fm [6] and $a = 4.24 \pm 0.29 + i\,0.72 \pm 0.81$ fm [7] with intriguingly small imaginary parts. This is somewhat surprising, since ad hoc one might naively expect absorption on three nucleons to be three times as much as on a single nucleon and $\Im a \geq 1$ fm. Further, in addition to elementary absorption $\eta N \to \pi N$ there are new channels, notably absorption on two or three nucleons.

Ref. [8] considers several of these contributions. Firstly, it is pointed out that the presumably dominant part of quasifree elementary absorption (assumed to be coherent from a bound state extending all over the nucleus) should be proportional to the total isospin operator on the nucleons. Therefore, in the case of ^{3}He this would give essentially the same result as a single nucleon, not three times as much. Consideration of nuclear inelasticities on two or three nucleons are seen to be also small, even negligible in comparison with quasifree absorption. Absorption where the nucleus remains intact $\eta^3\mathrm{He} \to \pi^+ t$ was seen to be small already in Ref. [6].

Consequently, there does not seem to be any pressing need for $\Im a$ much larger than in the elementary ηN case in agreement with [6] and [7]. Similar arguments may be extended to other nuclei, too, probably improving the prospects of searches for bound states.

References

[1] C. Wilkin, Phys. Rev. C. **47**, R938 (1993).

[2] S. Wycech, A.M. Green and J.A. Niskanen, Phys. Rev. C **52**, 544 (1995).

[3] S.A. Rakityansky, S.A. Sofianos, M. Braun, V.B. Belyaev and W. Sandhas, Phys. Rev. C **53**, R2043 (1996).

[4] A. Fix and H. Arenhövel, Phys. Rev. C **66**, 024002 (2002).

[5] Q. Haider and L.C. Liu, Phys. Rev. C **66**, 045208 (2002).

[6] A. Sibirtsev, J. Haidenbauer, C. Hanhart, and J. A. Niskanen, arXiv:nucl-th/0310079, Eur. Phys. Journal A **22**, 495 (2004).

[7] A.M. Green and S. Wycech, Phys. Rev. C **68**, 061601(R) (2003).

[8] J. A. Niskanen, arXiv:nucl-th/0508021.

2.10 Issues in $np \to \eta d$ near threshold

H. Garcilazo [(1)] and M. T. Peña [(2)]

(1) Instituto Politécnico Nacional, Edificio 9, 07738 México D.F., Mexico
(2) Instituto Superior Técnico, Av. Rovisco Pais, P-1049-001 Lisboa, Portugal

The $np \to \eta d$ cross section near threshold was measured in Refs. [1,2]. The model to describe this process has been described in detail in Refs. [3-7]. Our main conclusion was that in order to explain the energy dependence of the $np \to \eta d$ cross section near threshold the real part of the ηN scattering length must be between 0.42 and 0.72 fm. In this talk we will concentrate on three issues: i) Effect of the σ width. Our three-body model is based in the meson-nucleon two-body channels ηN-πN-σN where the σN channel represents the inelastic $\pi\pi N$ channel and it has been included as an effective channel since the σ was taken to be a stable particle of mass $m_\sigma = 2m_\pi$. We have now shown that taking the σ as a $\pi\pi$ resonance with mass and width determined by the $I = J = 0$ phase shift [8] does not change qualitatively the results. ii) Can one pin-down the ηN scattering length? The seven models of the ηN amplitude that we use have been obtained in Refs. [9-12]. They are characterized by having $Re(a_{\eta N})$=0.42, 0.72, 0.75, 0.83, 0.87, 1.05, and 1.07 fm where $a_{\eta N}$ is the ηN scattering length which together with the effective range $r_{\eta N}$ and shape parameter $s_{\eta N}$ describe the ηN scattering amplitude at low energies. We consider $Re(a_{\eta N}) = x$ and take $Im(a_{\eta N})$, $Re(r_{\eta N})$, $Im(r_{\eta N})$, $Re(s_{\eta N})$, and $Im(s_{\eta N})$ as functions if x which allows us to generate models of the ηN amplitude for arbitrary values of x. Repeating our analysis with these fictitous models we conclude that $0.47 \leq Re(a_{\eta N}) \leq 0.64$ fm. iii) Quasivirtual versus quasibound ηNN state. In order to clarify the nature of the pole near threshold present in the ηNN system we calculated the ηd elastic scattering amplitude [7] and obtained from it the effective-range parameters $a_{\eta d}$, $r_{\eta d}$, and $s_{\eta d}$. Using this effective-range expansion we then located the nearest pole in the complex q-plane and found in all cases that the pole is located in the third quadrant which means that it is a quasivirtual state.

References

[1] H. Calén *et al.*, Phys. Rev. Lett. **79**, 2642 (1997).

[2] H. Calén *et al.*, Phys. Rev. Lett. **80**, 2069 (1998).

[3] H. Garcilazo and M. T, Peña, Phys. Rev. C **66**, 034006 (2002).

[4] H. Garcilazo and M. T. Peña, Phys. Rev. C **72**, 014003 (2005).

[5] H. Garcilazo and M. T. Peña, Phys. Rev. C **63**, 021001 (2001).

[6] H. Garcilazo, Phys. Rev. C **67**, 067001 (2003).

[7] H. Garcilazo, Phys. Rev. C **71**, 048201 (2005).

[8] C. D. Frogatt and J. L. Petersen, Nucl. Phys. **B129**, 89 (1977).

[9] A. Sibirtsev, S. Schneider, Ch. Elster, J. Haidenbauer, S. Krewald, and J. Speth, Phys. Rev. C **65**, 044007 (2002).

[10] M. Batinić, I. Šlaus, A. Švarc, and B. M. K. Nefkens, Phys. Rev. C **51**, 2310 (1995); M. Batinić, I. Dadić, I. Šlaus, A. Švarc, B. M. K. Nefkens, and T.-S. H. Lee, Physica Scripta **58**, 15 (1998).

[11] A. M. Green and S. Wycech, Phys. Rev. C **55**, R2167 (1997).

[12] A. M. Green and S. Wycech, Phys. Rev. C **60**, 035208 (1999).

2.11 Chiral approach to η in a nuclear medium

E. Oset

Departamento de Física Teórica and IFIC, Universidad de Valencia

Basic elements of chiral dynamics implementing unitarity in coupled channels were presented, in particular for the case of the interaction of the octet of pseudoscalar mesons and the octet of stable baryons, which leads to a set of dynamically generated resonances, like the $\Lambda(1405)$, $\Lambda(1670)$, $N^*(1535)$, etc. [1, 2, 3]. The $N^*(1535)$ resonance appears with a width of about 95 MeV, like proposed at BES [4], which is narrower than in other approaches. The discussion focused on whether the models that lead to large widths of the $N^*(1535)$ by making fits to the data could not give results equally acceptable by making constraint fits with the $N^*(1535)$ width given by the precise BES experiment.

With this chiral model where the $N^*(1535)$ is dynamically generated and one gets reasonable results for the ηN interaction, one constructs an η nucleus optical potential which has a manifest energy dependence [5], qualitatively similar to another one obtained on more phenomenological grounds [6], and with this potential one solves the Klein Gordon equation searching for bound η states in different nuclei. This is done in [7] with the result that there are indeed bound states in nuclei heavier than ^{12}C, but probably also lighter where it was not checked, but the widths are inevitably larger than the energy separation between the levels, what should make the identification of these states a non trivial task.

To finish the discussion a call was made to the paper of Nagahiro, Jido and Hirenzaki [8] where the production of η bound states is studied theoretically by means of the recoilless $(d,^3He)$ reaction. It is found there that the spectra does not show any visible sign of the bound states because they are so broad, and on the other hand a peak structure with a width of about 30 MeV is generated because of the recoilless $(d,^3He)$ reaction, which magnifies the cross section where the recoil momentum is about zero, and makes it decrease to lower and higher energies as one diverts from the magic recoilless kinematics. This should serve as a warning that not every peak seen in an experiment looking for bound η has to correspond to a bound state. On the other hand this paper also shows that the shapes of the cross section depend on the size of the optical potential, so, hopes are given that indirectly, but not through the peak structure, one might come to learn something about the interaction of η with nuclei.

References

[1] E. Oset and A. Ramos, Nucl. Phys. A **635** (1998) 99 [arXiv:nucl-th/9711022].

[2] E. Oset, A. Ramos and C. Bennhold, Phys. Lett. B **527** (2002) 99 [Erratum-ibid. B **530** (2002) 260] [arXiv:nucl-th/0109006].

[3] T. Inoue, E. Oset and M. J. Vicente Vacas, strangeness Phys. Rev. C **65** (2002) 035204 [arXiv:hep-ph/0110333].

[4] J. Z. Bai *et al.* [BES Collaboration], Phys. Lett. B **510** (2001) 75 [arXiv:hep-ex/0105011].

[5] T. Inoue and E. Oset, Nucl. Phys. A **710** (2002) 354 [arXiv:hep-ph/0205028].

[6] M. Post, S. Leupold and U. Mosel, Nucl. Phys. A **741** (2004) 81 [arXiv:nucl-th/0309085].

[7] C. Garcia-Recio, J. Nieves, T. Inoue and E. Oset, Phys. Lett. B **550** (2002) 47 [arXiv:nucl-th/0206024].

[8] H. Nagahiro, D. Jido and S. Hirenzaki, Phys. Rev. C **68** (2003) 035205 [arXiv:nucl-th/0304068].

2.12 η Photoproduction on the Nucleus[3]

U. Mosel[4]

Institut für Theoretische Physik, Universtät Giessen, Giessen, Germany

Eta photoproduction on heavier nuclei has been studied in a model that takes both the primary interaction and the final state interactions (FSI) into account. This model contains 2 steps. In the first step the initial interaction of the incoming photon with any of the nucleons of the target nucleus is treated by using cross sections for photons interacting with free nucleons. In this step 'trivial' in-medium effects are taken into account, such as Fermi motion of the hit nucleon and Pauli-blocking. The mesons produced in this interaction are then propagated through the nuclear medium until they leave the nucleus. Essential for this step is that it allows not only for absorption of produced mesons, but also for elastic and inelastic rescattering. In the latter process channel-coupling effects are taken fully into account so that, for example, the finally observed eta has not necessarily been produced in a first interaction step, but can have been produced later through an inelastic rescattering process of an originally produced pion.

In this latter step of final state propagation in-medium selfenergies can be included and their effect can be studied. Selfenergies of the eta and the relevant nucleon resonances have been calculated in [1]. There it has been found that the in-medium changes of the selfenergy of the N(1535) are relatively minor, the biggest contribution coming from the small ρ decay branch of this resonance that opens up when the ρ meson becomes softer in medium. In a selfconsistent coupling model [2] that involves various resonances and mesons relevant for this energy regime we find that η mesons in nuclei should experience an attractive potential of about -40 MeV that opening the possibility ofη bound states in nuclei.

The final state interactions have been modeled using the GiBUU semiclassical transport model [3]. The model has been compared with the TAPS data on nuclei [4, 1] and gives in general a good description of the experimental results as far as the total cross sections go. The data taken at higher energies exhibit a clear sensitivity to the in-medium potential of the N(1535) and in particular its momentum dependence. However, the energy-differential cross sections $d\sigma/dT_\eta$ still present a puzzle. Here the calculated distributions are shifted significantly to higher energies, compared to experiment [5]. This is true, when the FSI cross sections are taken consistently from a resonance model. Assuming instead a constant FSI cross section of $\sigma^{\eta}_{\mathrm{inel}} = 30$ mb does describe the data. An explanation for this problem is so far not available.

The importance of treating coupled channel effects correctly in the FSI becomes clearly visible in calculations for η electroproduction with virtual photons. Here our calculations show that while at the photon point secondary production processes are negligible, at higher virtualities of the incoming photon the process $\gamma + N \to \pi + N$, $\pi + N' \to \eta + N'$ becomes dominant [6, 7].

[3]Work supported by DFG

[4]mosel@physik.uni-giessen.de

References

[1] J. Lehr, M. Post and U. Mosel, Phys. Rev. C **68** (2003) 044601 [arXiv:nucl-th/0306024].

[2] M. Post, S. Leupold and U. Mosel, Nucl. Phys. A **741** (2004) 81 [arXiv:nucl-th/0309085].

[3] For details see: http://tp8.physik.uni-giessen.de:8080/GiBUU/

[4] A. Hombach, A. Engel, S. Teis and U. Mosel, Z. Phys. A **352** (1995) 223 [arXiv:nucl-th/9411025].

[5] M. Effenberger and A. Sibirtsev, from Nucl. Phys. A **632** (1998) 99 [arXiv:nucl-th/9710054].

[6] J. Lehr and U. Mosel, Phys. Rev. C **68** (2003) 044603 [arXiv:nucl-th/0307009].

[7] J. Lehr, M. Effenberger and U. Mosel, Nucl. Phys. A **671** (2000) 503 [arXiv:nucl-th/9907091].

2.13 Eta-meson production on the nucleon within the Giessen model [5]

V. Shklyar, H. Lenske, and U. Mosel

Institut für Theoretische Physik, Universität Giessen, D-35392 Giessen, Germany

In the Giessen model pion- and photon-induced reactions in the nucleon resonance energy region are described by an unitary coupled-channel effective Lagrangian approach [1-6] The coupled-channel problem is treated in the Bethe-Salpeter formalism where the interaction kernel is constructed from the effective interaction Lagrangians (see [6] and references therein). The K-matrix approximation is used to solve the Bethe-Salpeter equation maintaining unitarity as well as Lorenz and gauge invariance.

The resonance part of the interaction kernel relevant for the η-production consists of $S_{11}(1535)$, $S_{11}(1650)$, $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $P_{13}(1900)$, $D_{13}(1520)$, $D_{13}(1850)$, $D_{15}(1676)$, $F_{15}(1680)$, $F_{15}(2000)$ resonances. The resonance and background parameters are constrained by experimental data from a number of reactions: $\pi N \to \pi N$, $2\pi N$, ηN, ωN, $K\Lambda$, $K\Sigma$ and $\pi N \to \gamma N$, πN, ηN, ωN, $K\Lambda$, $K\Sigma$. The main difference to our previous calculations is the inclusion of higher partial waves with spin-$\frac{5}{2}$ which were omitted in [1-4]. The updated $\pi N \to \eta N$ and $\gamma p \to \eta p$ transition amplitudes are obtained by solving the multichannel problem as explained in [6-7]. Although the spin-$\frac{5}{2}$ resonances are found to be coupled only weakly to the final ηN final state [5], these contributions can be important for the description of the photon beam asymmetry because of interference effects.

Similar to our previous findings [3] the $\pi^- p \to \eta n$ reaction at c.m. energies 1.48...1.65 GeV is dominated by the S_{11}-partial wave contributions. Overall, the $S_{11}(1535)$-state plays the dominant role but above 1.65 GeV the destructive interference with the second $S_{11}(1650)$-resonance decreases the effective contribution from this partial wave. A similar behaviour was also found in the calculations of Jülich group [8]. In the present study the $P_{11}(1710)$-resonance is found to be completely inelastic. This state together with the background contributions dominate the $\pi^- p \to \eta n$ reaction at energies 1.6 .. 1.8 GeV.

A much larger database is available for the $\gamma p \to \eta p$ reaction [9-14]. In the energy region up to 1.75 GeV the η-photoproduction cross section on the proton is entirely dominated by the $S_{11}(1535)$ resonance contribution. At higher energies the photoproduction cross section is a sum of different partial waves without a single dominant partial wave. This conclusion is in line with findings of [15,16].

One of the major questions to be addressed in future studies are the magnitudes of the proton and neutron helicity amplitudes of the $S_{11}(1535)$-resonance. While MAID and Eta-MAID conclude on the same ratio of $A^n_{1/2}/A^p_{1/2} \approx 0.8$, the absolute value of the proton helicity amplitude is different in these studies. At the same time the GW-analysis of the pion photoproduction data [17] gives a smaller value for $A^n_{1/2}/A^p_{1/2} \approx 0.33$. We consider this as strong support for a combined analysis of pion- and eta-photoproduction in order to understand the property of this resonance. This study becomes even more interesting in view of forthcoming data on quasi-free eta-photoproduction on a neutron in a deuterium

[5] Supported by Forschungszentrum Juelich

target planned by CB-ELSA and GRAAL collaborations.

References

[1] T. Feuster and U. Mosel, Phys. Rev. **C58**, 457 (1998).

[2] T. Feuster and U. Mosel, Phys. Rev. **C59**, 460 (1999).

[3] G. Penner and U. Mosel, Phys. Rev. **C66**, 055211 (2002).

[4] G. Penner and U. Mosel, Phys. Rev. **C66**, 055212 (2002).

[5] V. Shklyar, G. Penner, and U. Mosel, Eur. Phys. J. **A21**, 445 (2004).

[6] V. Shklyar, H. Lenske, U. Mosel, and G. Penner, Phys. Rev. **C71**, 055206 (2005).

[7] V. Shklyar, H. Lenske, and U. Mosel, Phys. Rev. **C72**, 015210 (2005).

[8] A. M. Gasparyan, J. Haidenbauer, C. Hanhart, and J. Speth, Phys. Rev. **C68**, 045207 (2003).

[9] GRAAL, F. Renard *et al.*, Phys. Lett. **B528**, 215 (2002).

[10] CLAS, M. Dugger *et al.*, Phys. Rev. Lett. **89**, 222002 (2002).

[11] CB-ELSA, V. Crede *et al.*, Phys. Rev. Lett. **94**, 012004 (2005).

[12] B. Krusche *et al.*, Phys. Lett. **B358**, 40 (1995).

[13] B. Krusche *et al.*, Phys. Rev. Lett. **74**, 3736 (1995).

[14] J. Ajaka *et al.*, Phys. Rev. Lett. **81**, 1797 (1998).

[15] W.-T. Chiang, S. N. Yang, L. Tiator, M. Vanderhaeghen, and D. Drechsel, Phys. Rev. **C68**, 045202 (2003).

[16] W.-T. Chiang, S.-N. Yang, L. Tiator, and D. Drechsel, Nucl. Phys. **A700**, 429 (2002).

[17] R. A. Arndt, I. I. Strakovsky, and R. L. Workman, Phys. Rev. **C53**, 430 (1996).

2.14 Model dependence of the low-energy eta-nuclear interaction

A. Fix and H. Arenhövel

Institut für Kernphysik, Johannes Gutenberg-Universtät, Mainz, Germany

At present, our main knowledge about the low-energy ηN interaction is obtained from the analysis of $\pi N \to \pi N$, $\pi N \to \eta N$ and other reactions. A typical calculation is based on a coupled channel K- or T-matrix approach [1,2,3]. However, currently available models still provide quite weak constraints of the ηN amplitude. An alternative method to study the ηN interaction is to extract the corresponding information from η production data. Due to the short range nature of the main mechanisms of such processes the energy dependence of their cross sections is mainly governed by the long range part of the final state wave functions. This feature makes it possible to extract reliable information on low-energy η-nuclear scattering.

As an adequate way to embed the ηN dynamics into a microscopic η-nucleus calculation we solve the few-body scattering equations. This task is facilitated by using separable representations of the of the integral kernels. The approach allows one to reduce the dynamical equations to a numerically manageable form without significant loss of the basic physics. The reduction scheme is presented in [4,5,6] for the three-body system ηNN and in [7] for the η-$3N$ case.

The main question we have focused on is 'How sensitive are the few-body results to the details of the elementary ηN interaction?' This concerns primarily the part of the ηN phenomenology which are not well controlled by the ηN analyses. In order to understand the manner in which the properties of ηN interaction can influence η-nuclear phenomena the following issues were addressed:

- Sensitivity of the ηd scattering length $a_{\eta d}$ to the variation of the ηN amplitude $t_{\eta N}(\vec{p}, \vec{p}\,')$ at short distances in the ηN system.

- Dependence of $a_{\eta d}$ on the model for the $S_{11}(1535)$ resonance.

With respect to the first point, the matrix $t_{\eta N}(\vec{p}, \vec{p}\,')$ was modified through multiplication by the step functions $\theta(p - p_c)$ and $\theta(p' - p_c)$, so that $t_{\eta N}$ was set to zero if at least one of its momentum arguments exceeds the cut-off value p_c. We find a strong sensitivity of $a_{\eta d}$ for $p_c < 0.5$ fm^{-1} and essentially no dependence on p_c in the region $p_c > 1$ fm^{-1}.

For the second point, we compared the results for $a_{\eta d}$ obtained for three different models of the ηN interaction: (i) an isobar model in which S_{11} is mainly treated as a genuine baryon resonance [3], (ii) the potential model from [2], where the ηN resonance in the s-wave is generated through an artificial barrier in the ηN potential, and (iii) a dynamical model, where the $S_{11}(1535)$ is a quasibound $K\Sigma$ state appearing as a resonance in the ηN channel [8,9]. In each case the model parameters were fitted to the same value of the ηN scattering length and the same physical mass of the $S_{11}(1535)$ resonance. Our calculation shows that all three models lead to quite similar values of $a_{\eta d}$. As next step, we studied the sensitivity of the ηd scattering length to the ηN amplitude in different regions of the ηN energy E. Our

results showed that only a rather small region $-20 < E < 0$ MeV, where the ηN amplitude $f_{\eta N}$ is close to its zero energy value $a_{\eta N}$, is responsible for the resulting value of $a_{\eta d}$.

In view of the similarity of the ηd scattering length $a_{\eta d}$ arising from different ηN approaches and the irrelevance of the short range ηN dynamics we conclude that low-energy η-deuteron (and probably $\eta\,^3$He) properties are sensitive to the behavior of the ηN off-shell t-matrix only over a limited range of its momentum and energy arguments. This conclusion tells us that studies of ηNN and η-$3N$ phenomena will provide reliable information about the low-energy parameters of the ηN interaction.

References

[1] A. Green and S. Wycech, Phys. Rev. C 60, 035208 (1999); nucl-th/9905011

[2] V. Shklyar, H. Lenske, U. Mosel, Phys. Rev. C 72, 015210 (2005); nucl-th/0505010

[3] A.M. Gasparyan, J. Haidenbauer, C. Hanhart, and J. Speth, Phys. Rev. C 68, 045207 (2003); nucl-th/0307072

[4] N. V. Shevchenko, S. A. Rakityansky, S. A. Sofianos, V. B. Belyaev, and W. Sandhas, Phys. Rev. C 58, R3055 (1998)

[5] H. Garcilazo and M. T. Peña, Phys. Rev. C 61, 064010 (2001)

[6] A. Fix and H. Arenhövel, Nucl. Phys. A 697, 277 (2002)

[7] A. Fix and H. Arenhövel, Phys. Rev. C 66, 024002 (2003); Phys. Rev. C, 68 044002 (2003)

[8] N. Kaiser, T. Waas, and W. Weise, Nucl. Phys. A 612, 297 (1997); hep-ph/9607459

[9] T. Inoue and E. Oset, Nucl. Phys. A 710, 354 (2002); hep-ph/0205028

2.15 The role of dynamically generated resonances in η production

M. Döring[6], E. Oset, and D. Strottman

IFIC, University of Valencia, Spain

The unitary extensions of chiral perturbation theory $U\chi PT$ have brought new light in the study of the meson-baryon interaction and have shown that some well known resonances qualify as dynamically generated, or in other words, they are quasibound states of a meson and a baryon, the properties of which are described in terms of chiral Lagrangians. After early studies in this direction explaining the $\Lambda(1405)$ and the $N^*(1535)$ as dynamically generated resonances [1, 2, 3, 4, 5], more systematic studies have shown that there are two octets and one singlet of resonances from the interaction of the octet of pseudoscalar mesons with the octet of stable baryons [6, 7]. The $N^*(1535)$ belongs to one of these two octets and plays an important role in the πN interaction with its coupled channels ηN, $K\Lambda$ and $K\Sigma$ [8]. In spite of the success of the chiral unitary approach in dealing with the meson-baryon interaction in these channels, the fact that the quantum numbers of the $N^*(1535)$ are compatible with a standard three constituent quark structure and that its mass is roughly obtained in many standard quark models [9, 10], or recent lattice gauge calculations [11], has as a consequence that the case for the $N^*(1535)$ to be described as a dynamically generated resonance appears less clean than that of the $\Lambda(1405)$ where both quark models and lattice calculations have shown systematic difficulties[12].

In the model of [8] the $N^*(1535)$ appears as a dynamically generated resonance after fitting the subtraction constants of the intermediate meson-baryon loops to πN data in the channels S_{11} and S_{31}. It is remarkable that through the inclusion of the $\pi\pi N$ channel also the $\Delta(1620)$ appears as a pole in the complex plane of $\sqrt{s}$ in the S_{31} channel. The model gives also a good description of the $\pi N \to \eta N$ cross section near the ηN threshold (further above, the $N^*(1535)$ is a bit too narrow). This is a consequence of unitarity and the inclusion of the $\pi\pi N$ channel in the model: the latter channel is the only open inelastic channel relevant in the energy region of the $N^*(1535)$; as the $\pi\pi N$ channel is well described by the model, the reproduction of the $\pi N \to \eta N$ data is automatic. Thus, further information is desirable to isolate the molecular components of the $N^*(1535)$. In this context a calculation of the electro-production of the $N^*(1535)$ would offer an interesting and independent test of the model of [8].

In Ref. [13] it has been pointed out that the scattering length and effective range of the $\bar{K}K$ interaction give hints of the size of the molecular component of the $f_0(980)$. In particular, a positive effective range is a sign of a molecular state. For the $N^*(1535)$ the situation is different as in the unitary chiral model [8] this resonance appears as a quasibound state of the $K\Sigma$ and $K\Lambda$. However, for further studies the threshold parameters have been provided in the workshop and are displayed in Tab. 1 and 2. For a recent compilation on the ηN scattering length see Ref. [14].

[6]Email: doering@ific.uv.es

Channel	Re a [fm]	Im a [fm]	Re r_0 [fm]	Im r_0 [fm]
$K^+\Sigma^- \to K^+\Sigma^-$	-0.29	$+0.087$	$+0.58$	-1.50
$K^0\Sigma^0 \to K^0\Sigma^0$	-0.21	$+0.067$	-2.25	-0.36
$K^0\Lambda \to K^0\Lambda$	-0.15	$+0.17$	$+0.74$	-3.21
$\pi^-p \to \pi^-p$	$+0.080$	$+0.003$	-14.7	-22.3
$\pi^0 n \to \pi^0 n$	-0.023	0	-31.4	0
$\eta n \to \eta n$	$+0.27$	$+0.24$	-7.26	$+6.59$

Table 1: Scattering lengths a and effective range parameters r_0 calculated from the model [8].

Channel	a [fm]	$a_{\text{exp.}}$ [fm]	a [fm]
$K\Sigma \to K\Sigma$, $I = 1/2$	$-0.12 + i\,0.03$		$-0.15 + i\,0.09^{(*)}$
$K\Sigma \to K\Sigma$, $I = 3/2$	$-0.34 + i\,0.10$		$-0.13 + i\,0.04^{(*)}$
$K\Lambda \to K\Lambda$	$-0.15 + i\,0.17$		$+0.26 + i\,0.10^{(*)}$
$\pi^-p \to \pi^-p$	$+0.080 + i\,0.003$	$+0.123 \pm 0.02^{(**)}$	
$\pi^0 n \to \pi^0 n$	$-0.023 + i\,0$	$-0.004 \pm 0.006^{(***)}$	
$\eta n \to \eta n$	$+0.27 + i\,0.24$		$+0.43 + i\,0.21^{(*)}$ $+0.717 + i\,0.265^{(****)}$ $+0.20 + i\,0.26^{(*****)}$

Table 2: Scattering lengths a from unitary coupled channel approach [8] (second column), "experiment" (third column), other work (last column).

($*$) Lutz, Wolf,Friman, NPA **706**

($**$) Ericson, Loiseau, Wyech, hep-ph/0310134

($***$) M.Döring., Oset, Vicente Vacas, PRC **70**

($****$) A. Svarc

($*****$) Kaiser, Waas, Weise, **NPA 612**

In Refs. [15] and [16] the η production has been investigated for a larger set of pion- and photon-induced reactions. For the $\gamma p \to \pi^0 \eta p$ reaction the $N^*(1535)$ has again been found important, although cross section and invariant mass spectra are almost independent on the actual width of the resonance as it becomes clear when using a phenomenological $\pi N \to \eta N$ s-wave transition potential that exhibits a larger width.

At the energies of the $\gamma p \to \pi^0 \eta p$ reaction other resonances, which couple to the η, certainly play an important role. The $\Delta^*(1700)$ resonance qualifies as dynamically generated through the interaction of the 0^- meson octet and the $3/2^+$ baryon decuplet as recent studies show [17, 18]. In this picture it is possible [18] to obtain the coupling of the $\Delta^*(1700)$ to the $\eta\Delta(1232)$ and $K\Sigma^*(1385)$ for which experimental information does not yet exist. For the $\gamma p \to \pi^0 \eta p$ reaction this resonance turns out to play an important role. Comparing the predictions with preliminary data from [19], a good agreement is found. The $\Delta^*(1700)$ has been studied in [16] for the reactions $\pi^- p \to K^0 \pi^0 \Lambda$, $\pi^+ p \to K^+ \pi^+ \Lambda$, $K^+ \bar{K}^0 p$, $K^+ \pi^+ \Sigma^0$, $K^+ \pi^0 \Sigma^+$, and $\underline{\eta \pi^+ p}$, in which the basic dynamics is again given by the excitation of the $\Delta^*(1700)$ resonance which subsequently decays into $K\Sigma^*(1385)$ or $\Delta(1232)\eta$. In a similar way the $\gamma p \to K^0 \pi^+ \Lambda$, $K^+ \pi^- \Sigma^+$, $K^+ \pi^+ \Sigma^-$, and $K^0 \pi^0 \Sigma^+$ related reactions are studied. Besides a good description of the energy dependence of the cross sections in most of the reactions, for all reactions a good global agreement is found at energies up to around $s^{1/2} =$ 1930 MeV which is remarkable as the various cross sections differ by a factor of 50 for the pion-induced reactions and by a factor of 5-10 for the photon-induced ones. Thus, the data of the various three-body final states, among them $\eta \pi N$, gives support to the $\Delta^*(1700)$ being a dynamically generated resonance.

References

[1] N. Kaiser, P. B. Siegel and W. Weise, Phys. Lett. B **362** (1995) 23.

[2] N. Kaiser, T. Waas and W. Weise, Nucl. Phys. A **612** (1997) 297

[3] E. Oset and A. Ramos, Nucl. Phys. A **635** (1998) 99

[4] J. C. Nacher, A. Parreno, E. Oset, A. Ramos, A. Hosaka and M. Oka, Nucl. Phys. A **678** (2000) 187

[5] J. A. Oller and U. G. Meißner, Phys. Lett. B **500** (2001) 263

[6] D. Jido, J. A. Oller, E. Oset, A. Ramos and U. G. Meißner, Nucl. Phys. A **725** (2003) 181

[7] C. Garcia-Recio, M. F. M. Lutz and J. Nieves, Phys. Lett. B **582** (2004) 49

[8] T. Inoue, E. Oset and M. J. Vicente Vacas, Phys. Rev. C **65** (2002) 035204

[9] N. Isgur and G. Karl, Phys. Rev. D **18** (1978) 4187.

[10] S. Capstick and W. Roberts, Phys. Rev. D **49** (1994) 4570

[11] T. W. Chiu and T. H. Hsieh, arXiv:hep-lat/0501021.

[12] N. Nakajima, H. Matsufuru, Y. Nemoto and H. Suganuma, arXiv:hep-lat/0204014.

[13] V. Baru, J. Haidenbauer, C. Hanhart, Y. Kalashnikova and A. Kudryavtsev, Phys. Lett. B **586**, 53 (2004)

[14] A. Sibirtsev, S. Schneider, C. Elster, J. Haidenbauer, S. Krewald and J. Speth, Phys. Rev. C **65**, 044007 (2002)

[15] M. Doring, E. Oset and D. Strottman, Phys. Rev. C **73**, 045209 (2006)

[16] M. Doring, E. Oset and D. Strottman, arXiv:nucl-th/0602055, accepted for publication in Phys. Lett. **B**.

[17] E. E. Kolomeitsev and M. F. M. Lutz, Phys. Lett. B **585**, 243 (2004)

[18] S. Sarkar, E. Oset and M. J. Vicente Vacas, Nucl. Phys. A **750**, 294 (2005)

[19] M. Nanova at the "International Workshop On The Physics Of Excited Baryons (NSTAR 05)", 10-15 Oct 2005, Tallahassee, Florida

2.16 $\pi N \to \eta N$ reaction within the framework of the coupled-channels meson-nucleon model

A. Gasparyan[1*], J. Haidenbauer[2], and C. Hanhart[2]

[1]Institute of Theoretical and Experimental Physics, Moscow, Russia
[2]Institut für Kernphysik (Theorie), Forschungszentrum Jülich, Jülich, Germany

A coupled-channels meson-exchange model for the elastic and inelastic πN scattering developed by the Jülich group is presented [1]. The model includes channels πN, ηN, as well as three effective $\pi\pi N$ channels namely ρN, $\pi\Delta$, and σN. The model is based on the effective potential, containing t-,u-, and s- channel exchange diagrams. This potential is used then in the Lippmann-Schwinger equation in order to obtain the scattering amplitude. The goal is to describe the πN data not only close to πN threshold but also in the resonance region.

There exist many models describing πN scattering in the resonance region. Those include simple resonance parameterization [2], K-matrix approximation [3], separable models [4], and chiral coupled-channel approach [5,6,7]. Compared to most of them, the advantages of the Jülich model are that the background is fitted to all partial waves simultaneously and that resonances can be generated dynamically (in particular, the Roper resonance is generated due to a strong interaction in the σN channel) or they can be included as bare s-channel poles.

The resulting phase shifts and inelasticities for isospin 1/2 and 3/2 and $j \leq 5/2$ partial waves describe the empirical data [8] rather well up to the c.m. energy 1900 MeV. The total $\pi N \to \eta N$ cross section [9-13] is also well reproduced. It turned out that the $\pi\pi N$ channel is necessarily needed if one wants to simultaneously describe the $\pi N \to \eta N$ cross section and the S_{11} inelasticity in the πN channel. One gets for the ηN scattering length (which is a very important quantity in the η-nucleus physics) the value $a_{\eta N} = 0.4 + i0.25$ fm. The $\pi N \to \eta N$ differential cross section [9,12,13] is reproduced up to the energies around 1650 MeV. At higher energies the agreement with the experimental data is worse. A possible explanation for that is the need to include higher partial waves coupling to the ηN channel.

For the consistency of the model the ωN channel and strangeness channels also have to be included. The work along this line is in progress now.

References

[1] A. M. Gasparyan, J. Haidenbauer, C. Hanhart and J. Speth, Phys. Rev. C **68**, 045207 (2003).

[2] K. Tsushima, S. W. Huang and A. Faessler, Phys. Lett. B **337**, 245 (1994).

[3] G. Penner and U. Mosel, Phys. Rev.C65 055202(2002).

[4] M. F. M. Lutz, G. Wolf and B. Friman, Nucl. Phys. A **706**, 431 (2002).

[5] N. Kaiser, P. B. Siegel and W. Weise, Phys. Lett. B **362**, 23 (1995).

[6] T. Inoue, E. Oset and M. J. Vicente Vacas, Phys. Rev. C **65**, 035204 (2002).

[7] E. E. Kolomeitsev and M. F. M. Lutz, Phys. Lett. B **585**, 243 (2004).

[8] R.A. Arndt, I.I. Strakovsky, R.L. Workman and M.M. Pavan, Phys. Rev. C **52**, 2120 (1995).

[9] R.M. Brown et al., Nucl. Phys. B **153**, 89 (1979).

[10] F. Bulos et al., Phys. Rev. Lett. **13**, 486 (1964).

[11] F. Bulos et al., Phys. Rev. **187**, 1827 (1969).

[12] W. Deinet et al., Nucl. Phys. B **11**, 495 (1969).

[13] B.W. Richards et al., Phys. Rev. D **1**, 10 (1970).

2.17 Three-body model calculations for the final state of the $np \to \eta d$ reaction near threshold

M. T. Peña [(1),*] and H. Garcilazo [(2)]

(1) Instituto Superior Técnico, Av. Rovisco Pais, P-1049-001 Lisboa, Portugal
(2) Instituto Politécnico Nacional, Edificio 9, 07738 México D.F., Mexico

We present in this talk the results of three-body model calculations [1,2] for the $np \to \eta d$ reaction near threshold. Since the existing empirical knowledge of the ηN interaction and S11-N*(1535) resonance provides a dispersion of the ηN scattering length in the interval 0.27fm $\leq \mathrm{Re}(\mathrm{a}_{\eta\mathrm{N}}) \leq$ 1.05fm, our calculations probed different ηN dynamical models, based upon recent data analysis of the coupled reactions $\pi N \to \eta N$, $\eta N \to \eta N$ and $\gamma N \to \eta N$ [3-6].

For each model, the short-range production mechanism strength was fitted to the very-near-threshold region, and from there the cross section at higher energies was predicted. Only the Jülich model [3] describes the data reasonably well throughout the full energy range. The preference of the data for a model with small $\mathrm{Re}(a_{\eta N})$, as the Jülich model, is to a large extent independent of the production mechanism, and our results show that the characteristic shape near threshold of the experimental cross section is a signature of the ηd final-state interaction. On the contrary, the absolute value of the cross section depends on the production mechanism.

In this presentation we also report how these results are modified by a relativistic treatment for the kinematics of the 3 particles involved, and the boosts of the two-body interactions. In common, both the relativistic and non-relativistic calculations show that the shape of the cross-section is essentially determined by the ηd three-body final state interaction alone. The relativistic calculation indicates that the description of the $np \to \eta d$ reaction near threshold implies that the ηN scattering length is in the interval $0.42 < a_{\eta N} < 0.72$fm. In the following lecture by Humberto Garcilazo, it is shown how to narrow this uncertainty interval.

References

[1] H. Garcilazo and M. T, Peña, Phys. Rev. C **66**, 034006 (2002).

[2] H. Garcilazo and M. T. Peña, Phys. Rev. C **72**, 014003 (2005).

[3] C. Hanhart, J. Haidenbauer, O. Krehl, J. Speth, Phys. Lett. B**444** 25 (1998).

[4] M. Batinić, I. Šlaus, A. Švarc, and B. M. K. Nefkens, Phys. Rev. C **51**, 2310 (1995); M. Batinić, I. Dadić, I. Šlaus, A. Švarc, B. M. K. Nefkens, and T.-S. H. Lee, Physica Scripta **58**, 15 (1998).

[5] A. M. Green and S. Wycech, Phys. Rev. C **55**, R2167 (1997).

[6] A. M. Green and S. Wycech, Phys. Rev. C **60**, 035208 (1999).

2.18 An Isobar Model for η Photo- and Electroproduction on the Nucleon

L. Tiator

Institut für Kernphysik, Universtät Mainz, Mainz, Germany

ETAMAID is an isobar model for eta photo- and electroproduction on the nucleon. It is available as an online program on the web [1] for easy access and individual studies of model parameters and kinematical conditions.

The isobar model contains a field-theoretical background with s- and u-channel nucleon Born terms and ρ, ω-exchange in the t-channel. In the resonance sector eight nucleon resonances in Breit-Wigner form can be selected with fixed resonance parameters, $S_{11}(1535)$, $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$, $D_{13}(1520)$, $D_{13}(1700)$, $D_{15}(1675)$ and $F_{15}(1680)$ [2,3]. This model describes almost all of the existing data of eta photoproduction on the proton from MAMI [4,5], ELSA [6,7,8], GRAAL [9,10,11] and CLAS [12] very well. Only the target polarization data from Bonn [7] near threshold is in disagreement with our isobar model, and all other existing models as well. Electroproduction data from JLab [13,14] are also well described and determine the transition form factor of the $S_{11}(1535)$ resonance very precisely. This transition form factor is an exception among all other form factors, as it drops down with Q^2 very slowly. In fact, it even rises against the standard nucleon dipole form factor.

Very recently, both at GRAAL [15] and at CB-ELSA [16] eta photoproduction was measured on the deuteron, allowing a separation of proton and neutron data in the range of $W_{thr.} < W < 2$ GeV. In both experiments a bump was observed in the neutron cross sections near $W = 1675$ MeV. This bump can be reasonably well described with ETAMAID, however, only because of a rather strong $D_{15}(1675)$ resonance with a branching ratio into the ηN channel of $\beta_{\eta N} = 17\%$. Alternatively, the bump can also be described with a narrow $P_{11}(1675)$ resonance, following the suggestion by Polyakov [17,18,19], who predicted such a state as a non-strange member of the Θ^+ pentaquark decuplet. In collaboration with Alexander Fix in Mainz [20] we have shown that such a narrow resonance with a total width of only about 10 MeV will give similar results as the much broader D_{15} resonance with a total width of 150 MeV, when it is Fermi averaged in a quasifree production process using deuteron wave functions.

Even if both pictures can lead to very similar total cross sections, in angular distributions of cross sections and polarization observables they can lead to rather different shapes due to interferences with different multipoles, most likely with the dominant S_{11} partial wave. A first comparison with preliminary angular distributions from CB-ELSA at $W = 1025$ MeV and 1075 MeV leads to the finding that the conventional D_{15} model is in a qualitatively better agreement than the narrow P_{11} model.

References

[1] http://www.kph.uni-mainz.de/MAID/

[2] W.-T. Chiang, S.N. Yang, L. Tiator and D. Drechsel, Nucl. Phys. A 700, 429 (2002).

[3] W.-T. Chiang, S.N. Yang, L. Tiator, M. Vanderhaeghen and D. Drechsel, Phys. Rev. C 68, 045202 (2003).

[4] B. Krusche *et al.*, Phys. Rev. Lett. 74, 3736 (1995).

[5] B. Krusche *et al.*, Phys. Lett. B 358, 40 (1995).

[6] J.W. Price *et al.*, Phys. Rev. C 51, 2283 (1995).

[7] A. Bock *et al.*, Phys. Rev. Lett. 81, 534 (1998).

[8] V. Crede *et al.*, Phys. Rev. Lett. 94, 012004 (2005).

[9] J. Ajaka *et al.*, Phys. Rev. Lett. 81, 1797 (1998).

[10] V. Kouznetsov, SAID database, GRAAL, 2001.

[11] F. Renard *et al.*, Phys. Lett. B 528, 215 (2002).

[12] M. Dugger *et al.*, Phys. Rev. Lett. 89, 222002 (2002); 89, 249904(E) (2002).

[13] C.S. Armstrong *et al.*, Phys. Rev. D 60, 052004 (1999).

[14] R. Thompson *et al.*, Phys. Rev. Lett. 86, 1702 (2001).

[15] V. Kouznetsov (for the GRAAL collaboration), Proc. of the NSTAR2005 Workshop, Tallahassee, FL, World Scientific, 2006.

[16] I. Jaegle (for the CB-ELSA collaboration), Proc. of the NSTAR2005 Workshop, Tallahassee, FL, World Scientific, 2006.

[17] D. Diakonov, V. Petrov, and M.V. Polyakov, Z. Phys. A 359, 305 (1997).

[18] M.V. Polyakov and A. Rathke, Eur. Phy. J A 18, 691 (2003).

[19] Ya. Azimov, V. Kouznetsov, M.V. Polyakov and I. Strakovsky, Eur. Phy. J A 25, 325 (2005).

[20] A. Fix and H. Arenhövel, Z. Phys. A 359, 427 (1997) and private communication.

3 List of Participants

- Vadim Baru <baru@itep.ru>, Institute of Theoretical and Experimental Physics, Moscow, Russia
- Michael Döring <michael.doering@ific.uv.es>, Departamento de Física Teórica and IFIC, Universidad de Valencia
- Goran Fäldt <goran.faldt@tsl.uu.se>, The Svedberg Laboratory, Uppsala, Sweden
- Alexander Fix <fix@kph.uni-mainz.de>, Institut für Kernphysik, Johannes Gutenberg-Universtät, Mainz, Germany
- Humberto Garcilazo <humberto@Gina.esfm.ipn.mx>, Instituto Politécnico Nacional, Edificio 9, 07738 México D.F., Mexico
- Ashot Gasparyan <gasparyn@itep.ru>, Institute of Theoretical and Experimental Physics, Moscow, Russia
- Johann Haidenbauer <j.haidenbauer@fz-juelich.de>, Institut für Kernphysik, FZ Jülich, Germany
- Christoph Hanhart <c.hanhart@fz-juelich.de>, Institut für Kernphysik, FZ Jülich, Germany
- Bo Höistad <bo.hoistad@tsl.uu.se>, Department of Radiation Sciences of Uppsala University, Uppsala, Sweden
- Daniil Kirillov <da.kirillov@fz-juelich.de>, Institut für Kernphysik, FZ Jülich, Germany
- Bernd Krusche <Bernd.Krusche@unibas.ch>, Department of Physics and Astronomy, University of Basel, Ch-4056 Basel, Switzerland
- Alexander Kudryavtsev <kudryavt@itep.ru>, Institute of Theoretical and Experimental Physics, Moscow, Russia
- Sasha Kvinikhidze <sasha_kvinikhidze@hotmail.com>, Mathematical Institute of Georgian Academy of Sciences, Tbilisi, Georgia
- Timo Mersmann <mersmat@uni-muenster.de>, Institut für Kernphysik, Universität Münster, Münster, Germany
- Ulrich Mosel <Ulrich.Mosel@theo.physik.uni-giessen.de>, Institut für Theoretische Physik, Universtät Giessen, Giessen, Germany
- Pawel Moskal <p.moskal@fz-juelich.de>, Institute of Physics, Jagellonian University, and IKP, Forschungszentrum Jülich
- Jouni Niskanen <jouni.niskanen@helsinki.fi>, Department of Physical Sciences, PO Box 64, FIN-00014 University of Helsinki, Finland

- Andreas Nogga <a.nogga@fz-juelich.de>, Institut für Kernphysik, FZ Jülich, Germany

- Eulogio Oset <oset@ific.uv.es>, Departamento de Física Teórica and IFIC, Universidad de Valencia

- Teresa Pena <teresa@fisica.ist.utl.pt>, Instituto Superior Técnico, Av. Rovisco Pais, P-1049-001 Lisboa, Portugal

- Vitaliy Shklyar <Vitaliy.Shklyar@theo.physik.uni-giessen.de>, Institut für Theoretische Physik, Universtät Giessen, Giessen, Germany

- Alexander Sibirtsev <a.sibirtsev@fz-juelich.de>, Institut für Kernphysik, FZ Jülich, Germany

- Aleksandr Starostin <starost@ucla.edu>, University of California, Los Angeles, CA 90095-1547, USA

- Hans Stroeher <h.stroeher@fz-juelich.de>, Institut für Kernphysik, FZ Jülich, Germany

- Alfred Švarc <svarc@irb.hr>, Ruđer Bošković Institute, Bijenička cesta 54, 10000 Zagreb, Croatia.

- Lothar Tiator <tiator@kph.uni-mainz.de>, Institut für Kernphysik, Johannes Gutenberg-Universtät, Mainz, Germany

- Colin Wilkin <cw@hep.ucl.ac.uk>, Physics Department, University College London, London WC1E 6BT, U.K.

- Magnus Wolke <m.wolke@fz-juelich.de>, Institut für Kernphysik, FZ Jülich, Germany

- Jozef Zlomanczuk <Jozef.Zlomanczuk@tsl.uu.se>, Department of Radiation Sciences of Uppsala University, Uppsala, Sweden.